METHOD AND SYSTEM FOR PROCESS GAS ENTRAINMENT AND MIXING IN A KILN SYSTEM

FIELD OF THE INVENTION

[001]   The present invention relates to a method and system for process gas entrainment and mixing in a kiln system. More particularly, it relates to a method and system in which a process gas flow is entrained by injected gas causing mixing of the process gas flow and facilitating the combustion and removal of chemical species present in the process gas flow during combustion in a kiln system.

BACKGROUND OF THE INVENTION

[002]   Kiln systems are known for processing cement clinker and various metallic and non-metallic minerals such as iron ore and lime. In this application, the text focuses on kiln systems for producing cement clinker, however, it will be understood by one of skill in the art that the concepts presented may have application in other types of kiln systems.

[003]   Cement clinker is the material that, when finely powdered forms cement, which is mixed with water and inert materials to form concrete and mortar. Cement clinker is conventionally produced by heating raw materials to very high temperatures in a kiln system. There are various types of kiln systems known in the art, including wet and dry "long" kiln systems and various types of preheater kiln systems. The following discussion will focus on preheater kiln systems however, similar processes occur in and similar difficulties may also arise in long kiln systems.

[004]   A conventional preheater kiln system used for the production of cement clinker generally consists of two sections, the preheater section and the kiln section. The preheating section consists of a gas riser duct and a series of cyclones, typically four or more in number mounted in a vertical structure, wherein the last cyclone in the series feeds into the kiln section via a feed chute.

[005]   The kiln section includes an inclined rotary kiln, which provides primary heating for the kiln system. The inclined rotary kiln includes a fuel inlet and flame at its lower end for heating the kiln. In some preheater kiln systems there may also be a secondary firing system in the gas riser duct or a precalciner (which is also sometimes referred to as a calciner), provided to calcine the majority of the raw material prior to entry to the kiln section. The precalciner may be provided between the preheating section and the kiln section but may also be a part of the preheater section.

[006]   For convenience, it is common practice to use a pair of cyclones in parallel at the uppermost stage of the preheater, and for high-throughput systems, a single kiln may have a complete set of "twin" preheater cyclones in series, with one or both of these "preheater strings" provided with a precalciner furnace or secondary firing system(s).

[007]   In a preheater kiln system, a mix of powdered raw material having the appropriate chemical composition ("raw meal") is fed into the uppermost cyclone. The raw meal used in the production of clinker in a conventional kiln system is conventionally prepared from natural quarried products that are principally comprised of limestone (a source of calcium carbonate), which is calcined to lime during heat treatment, with liberation of carbon dioxide via an endothermic reaction, and shale (a source of silicates, aluminates and iron oxide). When necessary, local reserves of raw materials are supplemented by corrective amounts of components such as sand (a source of silica), bauxite (a source of alumina), pyrites (a source of iron oxide) and/or limestone (often from higher purity reserves) to make up the raw meal. The raw material is finely ground and blended to form the raw meal before it is added to the uppermost cyclone.

[008]   The raw meal provides a basic chemical mixture that, when calcined and combined with ash from fossil or alternative fuels in the kiln system, allows for the formation - in an alumino-ferrite flux - of a blend of calcium silicates and

aluminates (called "clinker"). This is finely ground with addition of a set-control agent such as gypsum to form Portland cement, and when mixed with water, the silicates and aluminates undergo hydration reactions (i.e. set and grow in
5   strength to produce concrete or mortar).

[009]   When the raw meal is fed into the uppermost cyclone it is dispersed and pre-heated by a gas flow emanating from the next cyclone down in the series. Within each cyclone there is a vortex that disperses and collects the raw meal. The vor-
10 tex facilitates the movement of the raw meal from the first cyclone to the second cyclone in the series. As the raw meal moves down the cyclones it heats up and may partly calcine and, if combustible material is present, some of it may combust, ultimately leaving a final mixture known as kiln feed.
15 The vortex in each of the cyclones facilitates the movement of the raw meal down the series until it reaches the last cyclone. During the preheating stage, before the raw meal reaches the inclined rotary kiln, the temperature of the raw meal is raised to approximately 600 to 900 degrees Celsius
20 ($^{\circ}$C).

[010]   Once the raw meal passes through the last cyclone, it reaches the kiln hearth and (now referred to as "kiln feed") moves into the upper end of the inclined rotary kiln via a feed chute. Upon entering the inclined rotary kiln, the
25 kiln feed may also be referred to as hot meal. The hot meal progresses toward the lower end of the inclined rotary kiln in counter current to the gaseous products produced during fuel combustion at the lower end of the inclined rotary kiln.

[011]   As described above, the inclined rotary kiln has a
30 flame at the lower end of the incline (the "flame zone"), which heats the contents of the rotary kiln. The temperature of the hot meal is raised to approximately 1450 $^{\circ}$C before exiting the lower end of the rotary kiln. At this temperature the hot meal reaches a semi-molten state in which chemical reac-
35 tions take place, forming clinker. The flame and gas temperatures at the lower end of the inclined rotary kiln must be

considerably higher than 1450 °C to ensure that the hot meal reaches this temperature.

[012]   Once clinker is produced at the end of the inclined rotary kiln it flows into a clinker cooler where it is cooled by air. The hot air produced from the cooling of the clinker can then be reused to heat other sections of the kiln system, such as the preheater or the precalciner, in an effort to conserve energy. To move the hot air, the kiln system may be operated under negative pressure with exhaust gases being drawn through it under a draft induced by a fan. The fan may be located at or beyond the preheater exit.

[013]   In the kiln system, process gases travel up through the rotary kiln, gas riser duct and cyclones generally in counter current to the raw meal and may absorb many contaminants present. Prior to release to the atmosphere, the gases are typically dedusted to meet strict regulatory limits and if necessary are also cleansed of impurities such as NOx before release into the atmosphere.

[014]   A development in conventional preheater kiln systems is that fuel combustion may also take place in the secondary firing system (as described above), by supplying appropriately prepared fuel to the gas riser duct. This practice increases the throughput of a kiln system while having little effect on thermal efficiency. In addition, it also raises the degree of decarbonation ("calcining") of limestone entering the inclined rotary kiln, in turn reducing the thermal load on the flame zone of the kiln and often reducing the volume of combustion gases flowing through the rotary kiln.

[015]   In a further development, secondary firing may be extended to a greater degree in kiln systems fitted with a precalciner. A precalciner is an additional combustion vessel or furnace that is located at or near the base of the preheater where it is fed with appropriate fuel and air, preferably preheated. Preheated air for the precalciner may be taken from the exhaust produced from the clinker cooler, as described above. The preheated air can be moved by by-passing the rotary

kiln in an "air separate" system, where it is practical to do
so. Alternatively, the air may be received from the rotary
kiln in an "air through" variant.

[016]   Further advantages may accrue with the operation of
a precalciner, similar to those described above for riser duct
firing. One of the primary advantages is that the precalciner
allows for a greater scope and selection of operating condi-
tions, which in turn may allow for a reduction in the level of
oxides of nitrogen (NOx) passing through the preheater to the
atmosphere.

[017]   Another variation of a conventional kiln system in-
cludes the use of a grate pre-heater system, commonly referred
to as a "Lepol grate". Here, a finely ground raw meal mixture
is formed into nodules/pellets by the addition of water to a
rotating inclined dish. The pellets are then fed to the end of
a traveling grate where they are swept by the kiln exhaust
gases in order to be dried and preheated. Supplementary firing
may be done in and after the gas riser duct connecting the up-
per end of the kiln to the hot end of the grate, known as
"over grate firing". This process has benefits and problems
analogous to those that are described for the cyclone prehea-
ter systems, such as stratification of gases from combustion
in the various parts of the kiln system.

[018]   Clinker production makes intensive use of natural
resources, both in terms of energy and raw materials. Due to
the natural origin of the raw meal/kiln feed and fuels used in
a kiln system, minor amounts of other chemical species may
also enter the kiln system. These other chemical species can
enter in quantities that adversely influence conditions within
the kiln system. Furthermore, kiln systems produce an exhaust
gas stream that requires cleaning to ensure that any poten-
tially harmful chemicals that may be produced during the proc-
ess are reduced in concentration before the gas stream is re-
leased into the external environment and atmosphere.

[019]   Manufacturers are concerned with reducing their im-
pact upon the environment. For example, use of prime reserves

of raw materials and conventional fuels can be reduced by re-
ducing the consumption of energy derived from fossil fuels.
One way to reduce the use of prime reserves is by using alter-
native raw materials and/or alternative fuels, such as by-
products of agricultural, process and commercial enterprises.
These alternative substances can play a dual role in a kiln
system. Some of the alternative substances used as partial re-
placements for raw materials may bring a fuel content with
them and some alternative fuels may bring a significant con-
tent of ash, and as such play a dual role as both of these are
required in a kiln system. A consequence of using alternative
substances in lieu of traditional ones, however, can be that
additional organic matter and carbon may be present for com-
bustion in regions of the system other than the expected com-
bustion in flame zones.

[020]   A drawback to the use of either a conventional or an
alternative fuel (before processing "raw fuel"), is often the
need for prior expensive and energy-intensive preparation, ex-
amples of such would be the fine grinding of solids or the at-
omization of liquids. Accordingly, there is a desire to use
fuels effectively in the process and minimize the preparation
required. Alternatively, there is a further trend underway to
use fuels that are more difficult to burn (due to their hard-
ness, moisture content or adhesiveness) as long as undue addi-
tional expenses are not incurred in preparing them, and pro-
vided their dispersal and maintenance in a suitably oxidizing
gaseous medium (as required by their combustion characteris-
tics) is maintained. By way of example, this trend can be seen
in the techniques set out in various patents that deal with
the introduction of used vehicle tires into the upper end of
long kilns that are not generally equipped with preheaters. An
example is US Patent No. 5,078,594, issued to Cadence Chemical
Resources, Inc. and Ash Grove Cement Company.

[021]   The benefits of using alternative materials and fu-
els include reducing demands upon prime reserves and eliminat-
ing the problem of otherwise disposing of wastes and by-
products and the attendant effects upon the environment.

[022]   Kiln systems are well suited for the use of various
low-grade combustible coarse or lump fuels, because the ash
can be assimilated within the clinker product. The reason for
this is due to the fact that combustion occurs under con-
5   trolled and high temperature conditions, with significant
residence times for fuel particles at these temperatures.

[023]   Various difficulties arise in the operation of con-
ventional kiln systems, including pre-heater kiln systems when
using either traditional fossil fuels prepared according to
10   conventional methods and/or alternative fuels prepared by less
conventional means.

[024]   As a consequence, there may be limitations on the
amount of one or more fuels, in a given state of preparation,
that can be supplied to a precalciner, gas riser duct or upper
15   end of a kiln while still maintaining suitable clinkering
conditions at the lower/outlet end of the kiln system.

[025]   Conventional preheater kiln systems may have one or
more of the following difficulties: (a) a build-up of solid
material in the system resulting in either a partial or com-
20   plete blockage; (b) an increased generation of one or more
pollutants, such as NOx (or a limitation upon the degree of
abatement possible within the process); (c) an increase in en-
ergy consumption per tonne of product; and/or (d) a reduced
output rate.

25   [026]   Several of the above noted difficulties have the ad-
ditional disadvantage of limiting the possibilities for reduc-
ing consumption of prime fossil fuels with a consequent accom-
panying limitation of the scope for reducing the generation
and emission of greenhouse gases, such as carbon dioxide. Some
30   of the difficulties can, in principle, be alleviated by more
intensive pre-treatment and preparation of the fuel, in addi-
tion to using more complex procedures for its controlled de-
livery in the process. Implementing such solutions, however,
is often not cost-effective.

[027]   Ideally, when more fuel energy is put into some part of the kiln system, such as a preheater gas riser, which is downstream with respect to the combustion products, of the main burning zone, the result should be an increase in solid throughput where there is either no change or only a small change in the temperature of the gases emerging from that part of the kiln system. Higher exit gas temperatures would suggest that the extra energy has not all been efficiently applied to heat the solid materials, but has instead been wasted in creating and heating the gases.

[028]   Techniques intended to promote the beneficial mixing of gases in kiln systems are known, however, the levels of momentum and swirl involved are typically not large enough to be completely effective aerodynamically. Accordingly, the techniques that can have the most advantageous effect on the flow of gases and on heat transfer to and from the fuel and feed particles are not present in the parts of the process where they can best contribute to solving the problems that arise with respect to completion of combustion and other chemical reactions in kiln systems.

[029]   As such, there is a need for an improved method and system for process gas mixing in kiln systems in order to improve the combustion and environmental efficiency of kiln systems.

SUMMARY OF THE INVENTION

[030]   It is therefore an object of the present invention to provide an improved method and system for process gas mixing in kiln systems addressing at least some of the problems identified above.

[031]   In particular, an embodiment of the invention relates to a method and system for adding or injecting suitably-directed high momentum swirling turbulent gas to dust-laden stratified process gas at approximately 850 to 1400 °C to eliminate stratification and improve mixing of both process gases and suspended solids. The gas injection serves to en-

hance the contact of reacting materials, such as residual fuel
and available oxygen, and further serves to improve the com-
pletion of reactions, such as combustion of the fuel and the
transfer of heat to the raw meal/kiln feed/hot meal.

[032]   The projected benefits of the embodiments of the in-
vention include increased fossil fuel substitution, lower car-
bon monoxide emissions lower emissions of oxides of nitrogen,
ammonia and dioxins, higher levels of petroleum coke use and
increased clinker output.

[033]   According to an embodiment of the invention, there
is provided a system for mixing a process gas flow that is
flowing through a housing of a kiln system, the system for
mixing including at least one injector provided to the housing
and a gas supply system connected to the at least one injector
for supplying the gas to the injector at a predetermined pres-
sure, wherein the injector and the predetermined pressure are
arranged and selected to inject gas into the housing at suffi-
ciently high momentum to produce a jet having the appropriate
turbulent flow characteristics such that the process gas flow
is entrained by the injected gas.

[034]   According to another embodiment of the invention,
there is provided a system for mixing a process gas flow that
is flowing through a housing along an axis of the housing. The
system includes an injector provided in the housing and ap-
proximately on the axis and directed in the direction of proc-
ess gas flow and a gas supply system connected to the injector
for supplying gas to the injector at a predetermined pressure,
wherein the injector and the predetermined pressure are ar-
ranged and selected to inject gas into the housing at suffi-
ciently high momentum to produce a jet having the appropriate
turbulent flow characteristics such that the process gas flow
is entrained by the injected gases.

[035]   In either of the above embodiments, the injector may
be provided with swirl vanes and, in a preferred case, swirl
vanes having an angle of approximately 10 to 35 degrees. As an
alternative or in combination with the swirl vanes, the injec-

tor may also be provided with flare diffusers and/or a bluff
body to enhance the entrainment. Preferably, the flare diffus-
ers are at approximately 5 to 20 degree half angles.

[036]   In these embodiments, the system for injecting gas
is preferably arranged such that the process gas flow is sub-
stantially entrained before the injected gas flow is converted
to plug flow along with the process gas flow or before the in-
jected gas flow impinges upon the interior of the housing.

[037]   According to yet another embodiment of the inven-
tion, there is provided a system for mixing a process gas flow
that is flowing through a housing along an axis of the hous-
ing, the system including a plurality of injectors provided to
the housing and arranged at predetermined intervals around a
cross section of the process gas flow and in communication
with the interior of the housing, and a gas supply system for
supplying gas to the injectors at a predetermined pressure,
wherein the injectors are directed to inject gas to impinge
tangentially on a circle centered on the axis of the process
gas flow and covering at least approximately 5 to 15 percent
of the cross sectional area of the process gas flow.

[038]   In particular, the plurality of injectors and the
predetermined pressure are preferably arranged and selected to
inject gas into the housing at sufficiently high momentum to
produce a jet having the appropriate turbulent flow character-
istics such that the process gas flow is entrained by the in-
jected gas. In this case, the process gas flow is preferably
substantially entrained before the injected gas flow is con-
verted to plug flow along with the process gas flow or before
the injected gas flow impinges upon the interior of the hous-
ing.

[039]   In a preferred case, the circle covers at least ap-
proximately 5 to 10 percent of the cross sectional area of the
housing.

[040]   In the above embodiment, the injectors may be pro-
vided with swirl vanes and, in a preferred case, swirl vanes

having an angle of approximately 10 to 35 degrees. As an alternative or in combination with the swirl vanes, the injectors may also be provided with flare diffusers and/or a bluff bodies to enhance the entrainment. Preferably, the flare diffusers are at approximately 5 to 20 degree half angles.

[041]   In a further preferred case, the plurality of injectors are directed at an angle of approximately 0 to 60 degrees in the direction of process gas flow. In this case, the plurality of injectors may be further preferably directed at an angle of approximately 25 to 40 degrees in the direction of process gas flow.

[042]   In another preferred case, the plurality of injectors comprise a first set of injectors and the system further includes a second set of injectors including a least one injector which is provided to the housing, arranged at a second cross section of the housing and is in communication with the interior of the housing and the at least one injector is directed to inject gas to impinge tangentially on a second circle centered on the axis of the housing that has a different diameter than the circle of the first set of injectors. It will be understood by one of skill in the art that injection gas may be supplied to the second set of injectors by the same gas supply system as the first set of injectors or by a second gas supply system. Preferably, the second circle has a larger diameter than the circle of the first set of injectors and the second cross section is spaced apart from the cross section of the first set of injectors in the direction of process gas flow.

[043]   In the above embodiments, the injected gas may be, for example, air or oxygenated air or the like and the injected gases may be preheated depending on the particular application of the system.

[044]   In the above embodiments, the system may be applied to a kiln system for preparing cement clinker and, in particular, may advantageously be applied in a region of the kiln system where the process gas temperature is between approxi-

mately 850 to 1400 degrees Celsius. Depending on the location
of the system within the kiln system, for example, in a rotary
kiln, the process gas temperature may preferably be between
approximately 1000 to 1250 degrees Celsius, whereas in a re-
5   gion near a gas exit of a precalciner the gas temperature may
be between approximately 900 to 1250 degrees Celsius. Further,
when the system is applied such that said system will enhance
the efficiency and completion of reactions with ammonia, the
system is preferably applied in a region where the gas tem-
10 perature is between approximately 850 to 1050 degrees Celsius.

[045]   It will be understood that the various embodiments
of the system may be applied to a housing in one or more loca-
tions in a kiln system, for example, in the preheater section
including the gas riser duct or precalciner, an exhaust gas
15 by-pass system, or in the rotary kiln.

[046]   According to a further embodiment of the invention,
there is provided a method for mixing a process gas flow of a
kiln system including providing a source of injection gas at
high pressure, and injecting the injection gas into the proc-
20 ess gas flow at sufficiently high momentum to produce a jet
having appropriate turbulent flow characteristics such that
the process gas flow is entrained by the injected gas.

[047]   According to yet another embodiment of the inven-
tion, there is provided a method of mixing a process gas flow
25 in a housing of a kiln system including providing a source of
injection gas at high pressure, and injecting the injection
gas into the housing such that the injection gas impinges tan-
gentially on a circle centered on the axis of the process gas
flow and covering at least approximately 5 to 15 percent of
30 the cross sectional area of the process gas flow.

[048]   In a preferred case of the above two embodiments,
the method may include imparting swirl to the injection gas as
it enters the housing, for example, by using swirl vanes. Al-
ternatively or in combination, the turbulent flow and entrain-
35 ment may be enhanced by using flare diffusers and/or bluff
bodies.

[049]   In a further preferred case, the total momentum of the injection gas during injection is approximately 50 to 150% of the momentum of the process gas flow.

[050]   In another preferred case, the injection gas is injected at or above approximately 150 meters/second.

[051]   Preferably, the Reynolds Number due to the mixing is increased approximately 2.5 times above that encountered in a typical process gas flow without the mixing and in a similar region in a kiln system. Further, the turbulent frequency due to the mixing is preferably increased to approximately 100 times above that encountered in a typical process gas flow without the mixing. Still further, it is preferable if the total momentum, turbulence and swirl of the injected gases are selected based on an aerodynamic calculation and/or mathematical modeling indicating that the injected gas would substantially entrain the whole of the process gas flow.

[052]   Other embodiments of the present invention include a rotary kiln, precalciner, exhaust gas by-pass system, gas riser duct, or other appropriate component of a kiln system having the system for mixing a process gas flow described above applied thereto.

[053]   The mixing provided by the gas injection results in improved combustion of lump solid fuels (such as tires, wood and plastics) to encourage full, controlled and non-polluting combustion with energy release. The mixing provided by the gas injection also improves gas-to-particle heat transfer and makes better use of available oxygen in a kiln system.

[054]   Other aspects and features of the present invention will become apparent to those of ordinary skill in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[055]   The embodiments of the present invention shall be more clearly understood with reference to the following description of the preferred embodiments and to the drawings,
5   in which:

[056]   Fig. 1 illustrates a preheater kiln system;

[057]   Fig. 2 illustrates swirling air systems ("SAS") according to embodiments of the invention as applied to the preheater kiln system of Figure 1;

10 [058]   Fig. 3 illustrates a swirl air system located in a precalciner between the tertiary air and feed entries according to an embodiment of the invention;

[059]   FIG. 4 illustrates a cross-sectional top view of the swirl air system with injectors located at the periphery of a
15 rotating kiln section;

[060]   FIG. 5 illustrates a cross sectional view of a swirl air system located in a duct carrying dust-laden gases in a kiln system;

[061]   Fig. 6 illustrates a cross-sectional top view of a
20 swirl air system comprising two concentric contra-rotating swirl vortices according to another embodiment of the invention;

[062]   Fig. 7 illustrates a cross-sectional side view of the swirl air system of Fig. 5;

25 [063]   Fig. 8 illustrates a cross-sectional top view of a portion of a precalciner, forming part of the preheater kiln system comprising two concentric contra-rotating swirl vortices according to another embodiment of the invention;

[064]   Fig. 9 illustrates a portion of a kiln system in-
30 cluding the swirl air system of Fig. 8;

[065]   Fig. 10 illustrates an injector for the swirl air system of Fig. 6 and 7;

[066]   Fig. 11 illustrates a portion of a kiln system including a swirl air system according to another embodiment of the invention;

[067]   Fig. 12 illustrates a preheater kiln system with secondary firing supplied to the gas riser duct illustrating including two possible locations for a swirl air system according to embodiments of the invention; and

[068]   Fig. 13 illustrates an air-separate calciner kiln system including two possible locations for a swirl air system according to embodiments of the invention.

DETAILED DESCRIPTION

[069]   Figure 1 illustrates a typical preheater kiln 20 having a preheater section 22 and a kiln section 24. The preheater section 22 includes a raw meal feeder 26, which feeds raw meal to the uppermost cyclones 28a, 28b of a series of inter-connected cyclones 29a, 29b and 30 through which the raw meal passes, a gas riser duct 34 which transports gases from the kiln section 24 to the cyclones, and a feed shelf (or kiln hearth) 38, which is connected to the lowermost cyclone(s) and also connects the preheater section 22 to the kiln section 24. The preheater section also includes one or more exhaust fans 36, which maintain appropriate pressure levels within the preheater section 22 and the rotary kiln 42. The rotary kiln section 24 includes an inclined rotary kiln 42, which is connected via a seal 44 to the kiln hearth 38 at an upper end 46 of the rotary kiln 42, and a fuel feed 48, which is provided at a lower end 50 of the rotary kiln 42 and provides fuel to provide a flame 40 to heat the interior of the rotary kiln 42. The kiln section 24 further includes a clinker cooler 52 which is connected via a seal 54 at the lower end 50 of the rotary kiln 42 near the fuel feed 48.

[070]   In operation, raw meal travels via the raw meal
feeder 26 and enters into the first of the series of cyclones
28a and 28b. The raw meal is collected from the cyclones 28a
and 28b by vortex action and travels into a duct 56 that is
connected at the base of the cyclones 28a and 28b and then
proceeds to enter a subsequent cyclone for redispersal into
the gas stream. Eventually, the raw meal reaches the feed
shelf 38 by the action of gravity and of the cyclones. At the
same time that the raw meal is traveling through the preheater
section 22, hot process gases from the kiln section 24 are
rising through the gas riser duct 34 and through the cyclones
in a generally reverse direction to the flow of raw meal. As
such, the raw meal is heated as it is dispersed at each stage
in the hot process gases coming from the cyclone below or via
the gas riser duct 34 from the kiln section 24.

[071]   The hot raw meal on the feed shelf 38 (sometimes
called "kiln feed") then enters the kiln section 24 at the up-
per end 46 of the rotary kiln 42 where the kiln feed (now re-
ferred to as "hot meal") continues to travel through the ro-
tary kiln 42 by gravity and by the rotation of the rotary kiln
42, provoking mixture by sliding and tumbling. The hot meal
continues to be heated throughout this process undergoing
chemical reactions and forming clinker which eventually
reaches the lower end 50 of the rotary kiln 42 where it is
discharged into the clinker cooler 52 and cooled by a flow of
air. This air flow is typically also used in other parts of
the kiln system 20 to make use of the heat contained in the
air following exposure to the clinker.

[072]   In this conventional preheater kiln system 20, addi-
tional fuel may also be added into the gas riser duct 34 or
onto the feed shelf 38 of the preheater section 22 to provide
further preheating of the raw meal prior to entry to the kiln
section 24. Some fuel may also be added directly to the upper
end 46 of the rotary kiln 42, e.g., used tyres.

[073]   In a kiln system, the burning of fuel and the chemi-
cal reactions occurring in the raw meal and hot meal result in

the release of various chemical species into the process gas flow within the kiln system. Minor chemical species in a kiln system include compounds involving elements such as chlorine, sulphur, sodium, and potassium along with other elements within the same families. These are volatilized to a greater or lesser extent in the hotter regions of the kiln system and are carried in the process gas stream (sometimes also referred to as "process gas flow") to colder regions where they condense and where they may form solutions with low melting points. The volatile species may then bind particles of solid feed material together and bind to the ductwork in the kiln system. This process can lead to partial and/or major blockages and as a result the kiln system will require cleaning or other intervention to maintain the proper output. In some situations a permanent set of air blasters can be installed to curtail the problem of blockage.

[074]   Having condensed, some of the volatile species that do not bind to the ductwork may travel down to the hot regions in the kiln system again and undergo the volatilization process again. This cyclical pattern may increase the concentrations of volatile species and aggravate the attendant problems.

[075]   The degree of volatilization of the compounds may be affected by the following: (1) the composition of the local gaseous atmosphere; (2) coming into contact with other chemical species in the bed of solids; (3) the temperature of the kiln system; and/or (4) the behavior upon condensation. For example, the decomposition of calcium sulphate is affected by concentrations of oxygen and carbon monoxide, by contact with solid carbon, and by temperature. The decomposition of calcium sulphate can have unfortunate consequences when the amount of sulphur entering the kiln system is greater than that which can enter into combination with available (non-halide combined) alkalis as alkali sulphates. When this happens, the excess sulphur tends to react to form calcium sulphate or calcium-potassium-sulphate otherwise known as "calcium langbeinite" which are liable to decompose and volatilize as local

conditions vary. It is preferred that the sulphur leave the kiln with the clinker product in a stable chemically combined state, rather than decomposing, volatilizing and aggravating the recirculation, build-up and blockage phenomena.

[076]   Where extreme levels of circulating volatile compounds are encountered, it may be necessary to fit a by-pass system ("exhaust gas by-pass system"). This involves bleeding off a fraction of the rotary kiln exhaust from the gas riser duct via an off-take 80 of an exhaust gas by-pass system (not shown), quenching it to condense the volatiles and then removing them in a separate gas cleaning system that by-passes the preheater section.

[077]   Under certain conditions, halide species can be precursors in the formation of organic pollutants. Such conditions may exist when there are traces of organic impurities liberated from the raw meal and fuel being preheated. If suitable conditions of temperature, residence time and concentrations of chemical species exist, undesirable pollutants could then form and potentially be lost into the atmosphere once they condense onto dust or fume.

[078]   When oxidizing gases are not readily available, residual carbon ("char") from traces of solid fuel within the raw material components or from coarse or lump fuel used in secondary or precalciner firing may sometimes persist throughout the pre-heater 22 and enter the inclined rotary kiln 42. The combustion of the residual char may then produce local reducing conditions for sulphates, aiding in volatilization and inhibiting condensation. To avoid this occurrence, attempts have sometimes been made to operate the kiln system with a higher level of excess air than otherwise required. The extra air aids in the combustion of char but leads to energy losses due to the related heating of the nitrogen in the extra air. This adversely affects the potential for clinker output where output is limited by the capacity of the induced draft exhaust fan 36. Inadequate combustion in a secondary firing system,

such as precalciner 58, can also be a source of residual char
passing into the rotary kiln 42.

[079]   Gas riser duct firing typically does not achieve
useful gains in kiln throughput unless there is adequate heat
transfer to the solid material being processed. In practice,
this is seen for firing up to approximately 10 to 15% of fuel
in kiln systems where kiln fuel replacement by good quality
pulverized coal or oil at the secondary firing stage is used.
When gas riser duct firing is implemented, higher excess air
levels may need to be used to deal with other "difficult" low-
volatile fuels such as petroleum coke (known as "petcoke").
The higher excess air levels here work to ensure complete com-
bustion while keeping the probability of build-up acceptably
low, but, as discussed above, bring a wastage of energy in
heating the larger quantities of nitrogen in the extra air, as
well as a reduction in kiln output rate.

[080]   In addition to the above, when lower grade fuels are
used, extra air also needs to be passed through the kiln sys-
tem resulting in a reduction of the temperature of the main
flame 40. Accordingly, some or all of the extra energy will
not be transferred to the raw material and raw fuel, which in
turn results in a higher volume and temperature of exhaust gas
being handled by the induced draft fan 36. If the draft fan 36
lacks the capacity to cope with the required new duty, it may
further present a bottleneck in the kiln system 20 with re-
spect to increased output rates. In this situation, transient
carbon monoxide peaks may also be seen due to fuel quality or
feed rate variations, resulting in a generally higher level of
carbon monoxide emission from the system.

[081]   Carbon monoxide resulting from incomplete combustion
will tend to rise toward the uppermost layers of gas within
the rotary kiln 42, and it will not be positively mixed to re-
act with the residual oxygen present. Conversely to carbon
monoxide, carbon dioxide tends to be more highly concentrated
near the solid bed 66 in the rotary kiln 42. Upon leaving the
rotating kiln section 42, stratification of the gas may per-

sist into lower regions of a preheater and riser duct firing system. The stratification does not help the rapid complete combustion of raw fuel and more particularly lump fuel added at the kiln feed shelf 38 or where it is allowed to fall onto
5   the solid bed 66 at the upper end 46 of the rotary kiln 42, which is sometimes the practice for materials such as used tires.

[082]   Volatile chemicals liberated from a lump fuel as it ignites and burns enter the process gas flow and typically do
10   not have the opportunity to react with all the traces of oxygen present until later mixed in the preheater section 22 or precalciner 58. This often occurs at lower temperatures and as a result, traces of volatile hydrocarbons can sometimes emerge into the atmosphere as undesired pollutants. The undesired
15   pollutants may also be accompanied by higher than desired traces of unburned carbon monoxide. As described above, the conventional solution is to operate the kiln system at a higher level of excess air. This too has potential drawbacks that may limit the quantity of lump fuel that can be added at
20   the upper end 46 of the rotary kiln 42. A possible solution is to enrich the oxygen content of the combustion air (rarely an economic proposition) and/or to undertake major and costly reconstruction and enlargement of the kiln hearth 38 (if feasible) with an attendant loss of production during the modifica-
25   tions.

[083]   Another drawback in using lump fuels is that they can limit the potential use of high-sulphur fuels in the process, such as petroleum coke ("petcoke"), due to their influence on the decomposition, volatilization and deposition of
30   sulphates. Such petcoke is often cheaper to obtain because petcoke cannot be used easily in some types of boilers and processes that do not inherently absorb the extra sulphur.

[084]   There is a need to achieve a more complete and uniform burnout of char, carbon monoxide and volatile material
35   from "difficult" alternative fuels and to avoid operating kiln systems at unduly high and wasteful levels of excess air that

may impair throughput. Here, "difficult" refers to the idea that virtually all alternative fuels have one problem or another, either due to residual carbon due to initial size or/and lack of volatile matter (tires, wood chips, petcoke),
5   sudden volatile release due to either feeding (e.g., whole tires or bags/bales of commercial waste) or to high volatile contents (e.g. drill cuttings), or slow burnout (e.g., palm kernel shells, petcoke). Furthermore, it is possible that carbon dioxide concentrations in the boundary layer of process
10 gas around the raw meal and fuel in the precalciner 58 may be high, as well as high carbon monoxide levels in the process gas surrounding the fuel particles, given the process gas flow and turbulence conditions that normally prevail. High carbon dioxide or carbon monoxide concentrations may require operat-
15 ing the precalciner 58 (See Fig 13) at temperatures that are higher than ideally desired from the viewpoint of throughput and material reactivity. Residence times for effective mixing and combustion in many existing precalciners 58 are not suffi- cient to allow for the oxidation of all the carbon in slow
20 burning solid fuels. By increasing the temperature in the pre- calciner 58 it will also increase the exit temperature and change the location of regions where volatiles condense, often to non-accessible areas.

[085]   Stratification of process gas can arise within ducts
25 emerging from a precalciner 58 and in a precalciner 58 itself. Inadequate mixing in a precalciner 58 can lead to an increase in the temperature of the process gas emerging from the pre- calciner 58 for an apparently unchanged level of calcination of the raw feed. This is the average result from a non-uniform
30 mix of over-calcined and/or under-calcined material that even- tually may adversely affect clinkering reactions as well as patterns for deposition of sulphates.

[086]   As a result of stratification, attempts to reduce the concentration of nitrogen oxides ("NOx") via reburning re-
35 actions involving fuel injection at suitable process zones may fail to achieve their full potential, again leading to possi- ble undesired and unnecessary emissions. The NOx reburning re-

action involves the introduction of fuel and volatiles to a
process gas stream deficient in oxygen at a temperature be-
tween approximately 1000 to 1400 °C. The reaction is more effi-
cient at higher temperatures and lower levels of local
5   stoichiometry.

[087]   Another method to reduce NOx is by using a staged
combustion. This is achieved by allowing sub-stoichiometric
combustion of fuel volatiles, then afterwards introducing the
remaining oxygen to complete the combustion, serving to reduce
10   the concentration of NOx formed from the "Fuel NOx" reaction —
oxidization of nitrogen in the fuel. Appropriate mixing of the
solid and gaseous components in the reaction is advantageous,
both before and after staging.

[088]   For the further abatement of NOx, a selective non-
15   catalytic reduction ("SNCR") method can be used with the in-
jection of appropriate amounts of ammonia or ammoniacal com-
pounds (or solutions of these) at a suitable temperature and
in the presence of a certain range of oxygen concentration, as
this gas is involved in the chemical reaction as set forth:

20              $2NH_3 + 2NO + 0.5O_2 \Longleftrightarrow 2N_2 + 3H_2O$

[089]   The active component is the NH_2^* radical, which may
also be provided by alternative reagents. Theoretically, the
optimum temperature range for efficient reduction is between
approximately 850 to 1050 ºC. In practice, it is not always
25   possible to assure suitable complete reaction of the injected
ammonia by providing sufficient residence time for the react-
ing molecules at the appropriate conditions of gas temperature
and composition. A consequence will be the emission to atmos-
phere of undesired traces of ammonia and/or a failure to get
30   the emission level of oxides of nitrogen down to the desired
level. The ammonia emission presents a double problem in that
it may both infringe operating permits and lead to the forma-
tion of a dark-colored plume above the chimney stack. This
arises as the emitted gases cool, through formation of a fine
35   fume of ammonium salts (usually sulphate or chloride) that is
very effective at scattering light.

[090]   It has also been observed that the use of fuels that
are difficult to burn in secondary firing systems, such as
lump coal, or of fuel that is incompletely burned in the pre-
calciner **58**, can be associated with the detection of dioxins
and/or furans in dust from an exhaust gas by-pass system,
which allows the kiln operator to bleed off a fraction of the
exhaust as more fully described above (in which a proportion
of the gas stream is extracted, cooled and de-dusted to re-
moved condensed volatile compounds). This is attributed to un-
burned fuel, such as carbon or volatiles, being carried into
the off-take **80** and the exhaust gas by-pass system and acting
as drivers for the *de novo* dioxin synthesis reaction. It is
desirable to prevent such carry-over and use the fuel energy
productively.

[091]   There are a variety of geometrical designs of pre-
heaters **22** (including ducts and cyclones) and precalciners **58**
that may be connected to an inclined rotary kiln **42**. The use
of any specific variant in these descriptions is not intended
to limit the embodiment of the invention, but merely to indi-
cate general principles that can be applied to resolving prob-
lems in a kiln system. The same is true for the range of fuels
that may be used and methods of fuel preparation and delivery
to the kiln system. Additionally, although descriptions are
generally made on the basis of a symmetrical disposition of
equipment, practical difficulties may sometimes prevent this
from being achieved at a given location, and in such circum-
stances appropriate adaptations may be needed. Again, these
variations are not intended to limit the scope of the inven-
tion.

[092]   As will be evident from the following text, it is
useful to examine and attempt to overcome some of the problems
in conventional kiln systems through fluid dynamics.

[093]   A swirling air system ("SAS") **82** according to an em-
bodiment of the invention will first be described generally
with reference to **Figure 2** and will then be described in more
detail. Generally speaking, a SAS **82** according to an embodi-

ment of the invention is a system for injecting gases into the
process gas stream at sufficient momentum and turbulence to
jet entrain a substantial portion of the process gas stream to
provide mixing of the process gas stream and reduce or elimi-
5   nate stratification within the process gas stream.

[094]   As shown in **Fig. 2**, a SAS **82** may include either a
single injector **84** or multiple injectors **86** and may be placed
at various locations within the kiln system **20**. In a particu-
lar embodiment, an injector **84** is placed on the axis of the
10 kiln system, pointing in the direction of process gas flow (an
"axial SAS") **88**. The injector **84** is configured to create a
swirling vortex **90** within the process gas stream to cause mix-
ing of the process gas stream. In this example, the axial SAS
88 is axially located towards the upper end **46** of the rotary
15 kiln **42**, where the gas temperature is approximately 1200°C.

[095]   In another embodiment, also shown in Fig. 2, multi-
ple injectors **86** may be positioned around the periphery of a
housing **92** of an element of the kiln system **20**, for example,
the gas riser duct **34**, to inject gases across the process gas
20 flow (a "peripheral SAS") **94**. In this case, the injectors **86**
can be angled towards a specific central or tangential loca-
tion, for example, to a 0.3R (10% area) virtual circle in the
center of the process gas flow, to create an initial free vor-
tex **96** that decays with further turbulent mixing to a Rankine
25 vortex. Further, the injectors **86** may be inclined perhaps in
the range of 20° to 60° pointing upward in the direction of the
process gas flow. This arrangement allows for reburn of NOx
or CO to help eliminate or reduce these gases.

[096]   In general, an embodiment of the SAS **82** may be
30 placed in many areas of the kiln system 20. For example, in,
the gas riser **34**, the precalciner **58**, the exhaust gas by-pass
off-take **80**, or the rotary kiln **42**. In these cases, the SAS 82
may also be referred to as a "preheater SAS", "gas riser SAS",
"precalciner SAS" or the like.

35 [097]   Typically the details of each SAS **82** design will be
process and plant specific but are preferably based on the

rules of fluid dynamics for jet entrainment. Each SAS **82** is
designed using jet entrainment equations to generally provide
advantages to the particular installation involved. By way of
example, in the axial SAS **88**, all of the process gas down-
stream of the axial SAS **88** is generally fully entrained into
the jet flow before the new plug flow region. In the periph-
eral SAS **94**, a relative proportion of all the process gas is
generally entrained into each jet before their meeting point
in the central toroidal vortex **96** for greater mass and heat
transfer (e.g., a quarter of the process gas flow for each one
of four injectors).

[098]   As an example, the fluid dynamics equation used may
be:

$$Mj/Mo = [K1 \ (K2 \ +K3*S)*x]/[do*(Tf/To) \ ^{1/2}]$$

Where:

	Mj, Mo	total mass in jet at distance x, initial mass in jet
	K1	constant, depending on size of bluff body and degree of cross flow, range 1 to1.4
	K2	constant — 0.35 (experimentally derived)
	K3	constant — 4 (experimentally derived)
	S	swirl number of the injector
	x	axial distance
	do	effective injector diameter
	Tf	temperature of fluid to be entrained
	To	temperature of the jet fluid.

[099]   The actual design calculation for specific embodi-
ments of the SAS **82** may alternatively be determined using com-
putational fluid dynamics ("CFD") techniques. However, at the
time of writing, CFD is probably only of value for comparing
the effects of possible changes to the geometry or operation
of an existing system because CFD may not be able to predict

or model swirling flows as well as the application of the above equation due to the current inadequacy of turbulence models available for strongly swirling fluid flows.

[0100]   As described above, the SAS 82 is provided to inject a high momentum, swirling turbulent stream of air (or other gases) into the stratified gas and particle process gas flow at an area having a temperature of approximately 850-1400 °C in a kiln 42, gas riser 34, precalciner 58, or the like, in order to mix the process gas flow, remove the stratification and improve combustion and gas-to-particle heat transfer, making better use of available oxygen. The additional air — usually with a momentum level similar to that of the main process gas flow — arrives via injector(s) 84 or 86, designed specifically for the plant concerned.

[0101]   In a preferred embodiment, the injectors 84 and 86 may also be configured to induce swirl or turbulence in the injected gases and thereby enhance entrainment of the process gas flow. Figures 4 and 5 show alternative arrangements of the peripheral SAS 94, in which swirl vanes 100 are included within the injectors 84 and 86. The injectors 84 and 86 may also be provided with a bluff body (not shown) or flare diffuser (not shown). A bluff body is a centrally located solid disc or cone near the exit of the injector 84 or 86 of slightly smaller maximum diameter than the injector 84 or 86. The bluff body or flare diffuser additionally enhances jet entrainment.

[0102]   There are several advantages that may be observed when using a SAS 82 with a typical process gas flow. By way of example, the Reynolds number, which indicates turbulent flow and mixing, is expected to be approximately 2.5 times higher at some $7.5*10^5$ than in a typical main process gas flow, hence increasing turbulent mixing. In addition, the minimum eddy size is expected to be approximately 50 times smaller, that is, less than the size of particles of pulverized coal and raw material (around 3 microns), hence increasing heat transfer for both combustion and calcination. The turbulent frequency,

which indicates the rapidity of eddy fluctuations, is also expected to be generally increased by approximately 100 times or more from perhaps $1.5*10^5$ sec^{-1} to $5*10^7$ sec^{-1}, again facilitating mixing, combustion and heat transfer. Moreover, the jet

5   entrainment and mixing due to the swirl vanes **100** and/or flare diffuser or bluff body is expected to be approximately 2.5 times higher in a specific distance than for injection without such elements at the same velocity, hence the amount of air and fan pressure can be lower for the same effect and give a

10 more beneficial impact on both the installation and the process.

[0103]   It should be noted that normally, in cement kiln systems, values of Reynolds number, eddy size and turbulent frequency such as the above are found only in the main kiln

15 flame zone.

[0104]   Figure 3 illustrates the peripheral SAS **94** according to an embodiment of the invention. As described above, the peripheral SAS **94** may be applied to the gas riser **34** duct, the precalciner **58**, or to the rotary kiln **42** in the kiln system

20 **20**. As shown in Figure 3, the peripheral SAS **94** includes four injectors **86** directed into and across the process gas stream that is flowing through the gas riser duct **34** or the precalciner **58**. In particular, the four injectors **86** are directed tangentially to the 0.3R circle **98** representing approximately

25 10% of the area through which the process gas flows (sometimes referred to as a "virtual circle" because it is a targeted area within the process gas flow rather than an element of the kiln system **20**).

[0105]   In this embodiment, gases are injected tangentially

30 at a high momentum level to eliminate the stratification of gases at temperatures ranging between approximately 850 to 1400 °C. This embodiment of the invention also improves combustion, other chemical reactions and heat transfer to the solids, such as raw material and raw fuel in the kiln system. An

35 important factor in eliminating gas stratification which can lead to other improvements, is to achieve jet entrainment of

the majority of the process gas stream (preferably over 80%
and ideally 100%) into a new flow pattern in which turbulence
is enhanced and predominates, at temperatures favorable to the
chemical reactions. The concept is to create a jet mixed free
5   vortex flow of all the process gases that then decays with
further turbulent mixing to an intermediate vortex. The direc-
tion of gas injection is preferably neither directly axial nor
directly orthogonal to the flow direction of the process gas
stream. The gas injection is preferably aimed tangentially
10   from several injectors to one or more virtual circles cen-
trally located within the process gas flow. The virtual cir-
cle(s) should cover at least approximately 5% of the cross-
sectional area of the process gas flow at the region of injec-
tion. The injected gas may be air or oxygenated air, perhaps
15   preheated and optionally directed at an angle of up to ap-
proximately 60 degrees to the axial direction of gas flow. Ad-
ditionally, the gas injection may be carried out via injectors
86 optionally fitted with swirl vanes 100 at approximately 10
to 35 degree angles. Further, bluff bodies or flare diffusers
20   at approximately 5 to 20 degree half angles may also be added
to enhance jet entrainment. In a particular case, bluff bodies
or flare diffusers may be applied alone (i.e. without swirl
vanes), if the swirl vanes at the end of the injector(s) are
subject to blockages that may not so severely affect a simpler
25   device.

[0106]   As will be understood by one of skill in the art,
suitable materials for the construction and the protection of
the injector(s) 84 and 86 in the kiln system 20 must be con-
sidered, for example, steel alloys and/or refractory ceramics
30   that are able to withstand high temperatures are desirable.
Internal self-cooling systems (not shown) can also be in-
cluded.

[0107]   It may also be advantageous to include suitable
mounting systems to facilitate the maintenance and cleaning of
35   the injector(s) 84 and 86 in the kiln system 20. For example,
cleaning mechanisms may be added to dislodge any build-up of
chemical species, process fume and/or dust that may adhere to

a portion of the SAS **82** inside the kiln system **20**. Further, where injectors **84** and **86** do not protrude far into the process gas flow and have openings close to the interior lining of the housing, it may be necessary to fit traps for solid particles
5   along with an automatic means of removal of the trapped material.

[0108]   It will also be understood that the SAS **82** will include a gas supply system **102** (see **Figure 8**) including a fan or blower (not shown) (i.e. source of air) per injector or one
10 source of air per several injectors. The injected gases are preferably re-used from other parts of the kiln system **20** or other parts of the cement making process, where available.

[0109]   As a general guide, the gas momentum required for proper mixing of process gases is between approximately 50 and
15 150 percent (%) of the process gas flow. In order to minimise the amount of excess air injected into the system the velocity should be as high as possible, with a lower limit of approximately 150 m/s and preferably sonic or above. As a general guideline the approximate design criteria for a SAS **82** is a
20 momentum around 10 N/MW and the capability to entrain up to about 15 times the injected jet's own mass before reaching the centre of the process gas stream (for injection at or near the walls of the process vessel) or reaching the walls of the kiln (for injection on or near the axis). This involves a similar
25 level of mixing energy to that used in a high momentum pulverized fuel burner for a kiln or boiler. Preferably, the injection should be at sonic velocity or above, if possible, and will be commensurate to the available fan pressure. A more detailed SAS design is based on the jet entrainment laws for
30 swirling flows and bluff bodies, that take into consideration individual kiln, calciner, preheater, etc. geometries and mass flows and is aimed at achieving complete mixing via entrainment of the relevant process gas stream, before relevant impingement points either with the rotary kiln or other jet
35 streams.

[0110]   Preferably, directing the injected gases from several points towards the circumference of a virtual circle occupying approximately 10% of the central gas flow area will generally create a central mixing vortex. Adding a weak axial swirl to the injected gases will further enhance mixing, while avoiding the creation of an internal recirculation zone. For the most advantageous effect, the gases should be injected at openings flush with the walls of the kiln system so that they may traverse the maximum possible path length within the process gas stream. Some protrusion of the injectors may, however, be desirable to avoid blockages in situations where solid particles could enter the injectors if they are not kept out by the aerodynamics of the incoming gases or where there are external obstacles that make it impractical to have long straight lengths of injector outside the region of the kiln system concerned.

[0111]   Figures 6 and 7 illustrate another embodiment of the peripheral SAS 94. In this embodiment, a first swirl vortex 96 is generated as described above by injectors 86 directed to impinge tangentially on a virtual circle 98 of approximately 0.3R and is supplemented by a concentric contra-rotating swirl vortex 101, which is created by additional injectors 103 directed tangential to the circumference of a second virtual circle 104 in the process gas stream. In this case, injectors 86 may be aimed at a smaller diameter circle 98 located upstream in the process gas flow, so that an internal vortex 96 can develop prior to penetrating the larger diameter contra-rotating vortex 101 created by additional injectors 103 aimed at the larger virtual circle 104 as it expands to engulf the outer peripheral process gas flow. This will create both intense central mixing and extreme turbulence at the vortex boundaries. As above, swirl vanes 100 may be optionally used in the injectors to create yet further turbulence and bluff bodies or flare diffusers may also be added to further enhance the entrainment.

[0112]   Figures 8 and 9 illustrate a peripheral SAS 94 according to this embodiment of the invention. Figure 7 illus-

trates a cross-sectional view of a portion of a precalciner
58, forming part of a kiln system 20. In this case, the pre-
calciner 58 has a housing 92 that is circular in shape and ta-
pers inwardly at its lower end. The precalciner 58 includes

5   two coal lines 110 for feeding fuel into the housing 92. The
peripheral SAS 94 is provided to the housing 92 and includes a
set of four injectors 86 directed tangential to a virtual cir-
cle 98 located at the center of the precalciner 58 and cover-
ing approximately 10% of the area of the process gas flow.

10   These injectors 86 induce rotational motion of the process gas
flow traveling through the precalciner 58. The peripheral SAS
94 further includes a set of two injectors 103 directed tan-
gentially at a second virtual circle 104 at the center of the
precalciner 58 that is approximately twice the area of the

15   first virtual circle 98. In a preferred case, injectors 103
are offset axially along the direction of process gas flow by
a distance of approximately one precalciner radius from the
first virtual circle 98. These injectors 103 are arranged to
induce contra-rotating swirling of the process gas flow to the

20   swirling produced by the set of four injectors 86. The periph-
eral SAS 94 further includes a gas supply system 102 for de-
livering injection gas to the injectors 86 and 103.

[0113]   Figure 9 shows an elevation of the precalciner 58
showing that the injectors 86 are directed at an upward angle

25   of approximately 30° in this particular embodiment.

[0114]   Figure 10 illustrates an injector 86 of the type in-
cluded in the SAS 82. The injector includes a valve 112, a
pressure sensor (not shown - preferably installed in the in-
jector assembly, just outside the wall of the precalciner ves-

30   sel) and a nozzle 114, which extends through the housing 92.
In particular, there may be some benefit from having the noz-
zle outlet flush with the inside of the housing wall. The in-
jector 86 may also include an inlet 116 for compressed air to
purge the injector 86 of any potential blockage or the like.

35   As discussed above, depending on the embodiment and the type
of kiln system, the injector 86 may also be provided with

swirl vanes **100** or, optionally, a bluff body (not shown) or flare diffuser (not shown) to further enhance the entrainment.

[0115]   By way of exemplifying the principles involved, consider the set of chemical reactions involved in NOx reburning
5   where a preheater of a kiln system **20** with a 2000 tonne per day rating has NOx emission from the rotary kiln **42** to the preheater section **22** of 1200 ppm. If the stack emission from the kiln system **20** is to be below 500 mg/Nm3 (corrected to a 10% oxygen concentration, dry basis), part of the solution is
10 to reduce the kiln generated NOx significantly. In this example 20% secondary fuel is added to the process gas stream that has emerged from a primary flame operating at 10% excess air level. The resulting stoichiometry will be 0.85, which is close to the optimum level of 0.88 for NOx reduction in a 0.5
15 second residence time at a temperature of approximately 1200 °C or more preferably 1300 to 1400 °C. To ensure intimate contact of the chemical species involved after the reburning reaction, the SAS **82** can inject air to bring the stoichiometry up to 110% and ensure effective oxidation of carbon monoxide and re-
20 sidual hydrocarbons.

[0116]   The process gas flow rate for approximately 10% excess air can be calculated from the fuel consumption and carbon dioxide loss from the calcined raw fuel. The process gas velocity at a given temperature can then be assessed for a
25 given duct diameter giving its momentum. If this is used as the target total SAS momentum, a minimum required injection velocity can be assessed from the additional air quantity needed to reach the 15% overall excess air supply if an injected air temperature of 20 °C is assumed.

30 [0117]   Figure 11 shows the axial SAS **88** in more detail. The axial SAS **88** is useful to avoid possible problems with blockage of injectors located flush with the internal lining of the rotary kiln (i.e. like those in a peripheral SAS **94**) because the axial SAS **88** involves an injector **84** which is placed cen-
35 trally in the rotary kiln **42** and is directed in the same direction as the process gas flow (opposite in direction to the

raw meal). In this case, the injector 84 is preferably pro-
vided with 30° swirl vanes 100 and may also include a bluff
body or flare diffuser (as discussed above) and the injected
air is provided with enough momentum to entrain the process
5   gas flow as much as possible before the impingement point at
the kiln wall. This helps to ensure that the carbon in the
process gas flow is burned out and allows avoidance of high
sulphate-based build up in the kiln system 20. As shown in
Figure 11, the injector 84 may also be provided with a clean-
10   ing device 118 to remove any deposit build-up that may block
the injector 84.

[0118]   Figure 12 illustrates the location of a kiln SAS 120
or gas riser SAS 122 (both of which may be an axial SAS or a
peripheral SAS) in relation to the overall structure of a pre-
15   heater kiln system 20. In some cases, it may be useful to have
the SAS 82 in both the rotary kiln 42 and in the gas riser 34,
for example, when trying to use whole used tires in a reburn
reaction, a kiln SAS 120 can help avoid build-up problems and
a gas riser SAS 122 can help bring in the extra air to avoid
20   CO formation. If the SAS 82 is applied to the rotary kiln 42
it is preferably placed in an area where the gas temperature
is approximately 1200° C.

[0119]   Figure 13 illustrates the location of a kiln SAS 120
or calciner SAS 124 in relation to the overall structure of an
25   air separate precalciner kiln system 126. In Figure 13, the
kiln system 126 includes a tertiary air duct 128 which takes
heated air from the clinker cooler 52 to the precalciner 58
and thus is referred to as an air-separate precalciner kiln
system 126.

30   [0120]   The SAS 82 is intended to assist in overcoming typi-
cal combustion-related difficulties. Generally, these include
reducing the impact of lump fuel on sulphate-based build-up in
gas riser ducts 34, facilitating the use of petcoke with al-
ternative fuels such as tyres or other lump fuels, reducing
35   the level of CO and temperature produced at the exit of gas
risers and calciners when both conventional and alternative

fuels are used, reducing NOx, via reburning and/or staged com-
bustion, reducing ammonia "slip" in the SNCR de-NOx procedure,
and reducing the amount of trace dioxins or furans formed in
an exhaust gas by-pass system (although not all benefits will
5   necessarily be present at the same time). By way of example,
some of the benefits may be an increased use of more (or
coarser) alternative fuels and/or an increased use of alterna-
tive fuels at the same time as petroleum coke. The use of the
SAS 82 is also intended to contribute to resultant benefits
10   such as the substitution of more coal or oil by petcoke, the
lowing of CO emissions with the use of alternative fuels and
lower NOx emissions. The above intended benefits may be
achieved while attaining the goals of a higher clinker output
rate and the increased burn-out of fuel traces arriving with
15   raw materials.

[0121]. The installation of a kiln SAS 120, with an appro-
priate momentum, angle of swirl vanes 100, bluff body size or
flare diffuser so that a significant portion of the process
gas flow is entrained into the swirling flow, before the be-
20   ginning of a new plug flow zone in the rotary kiln 42 at ap-
proximately the end of the calcination zone (gas temperature >
1200°C), is expected to promote the combustion of the unburned
fuel in the process gas flow. The kiln SAS 120 is expected to
facilitate combustion in the process gas flow by making the O_2
25   concentration more uniform within the portion of the kiln sys-
tem that it is added to. In addition, the kiln SAS 120 should
facilitate the scrubbing away of the CO_2 layer that forms over
the hot meal in the inclined rotary kiln 42. In exposing the
unburned fuel more often to a higher O_2 concentration and by
30   stirring up the feed bed, combustion should be increased over-
all in the kiln system 20. (Although there may be practical
limits as to just how much dust recirculation can be toler-
ated).

[0122] By increasing the combustion in the process gas
35   flow, it should facilitate such things as the use of lower
levels of O_2 at the upper end 46 of the rotary kiln 42 for the
same level of substitution of conventional fuel by lump fuel.

This in turn should result in less impact on the clinker out-
put rate. In addition, it should facilitate the use of higher
and/or coarser levels of lump fuel for the same level of O_2 at
the upper end 46 of the rotary kiln 42.

[0123]   The installation of a kiln SAS 120 is also expected
to facilitate the use of petcoke with alternative fuels. The
advantage in using the SAS 82 is that the use of lump fuel
with petcoke generally produces a more severe build-up of sul-
phates, for the reasons described above, at even modest levels
of petcoke use. Therefore, the installation of a SAS 82 in the
kiln system at the end of the calcination zone should facili-
tate the use of higher levels of petcoke and/or a higher S
grade of petcoke.

[0124]   The installation of a gas riser SAS 122 or precal-
ciner SAS 124 is expected to reduce the exit CO and tempera-
ture level from gas riser ducts 34 and precalciners 58 with
alternative fuel usage. Due to higher volatile release rates
from alternative fuels and the stratification of the O_2 supply
from the kiln and the exhaust gas by-pass system, which in
turn leaves insufficient O_2 available locally to combust the
volatiles, in an excess of O_2, to produce sufficient OH radi-
cals to facilitate CO burnout; the introduction of lump fuel
alone (indeed, this also happens with pulverized coal to a
certain extent) to gas risers and calciners may produce in-
creases in CO and exit temperatures. This leads to the need
for higher riser duct 34 or precalciner 58 O_2 levels, leading
to increases in fuel consumption and decreases in clinker out-
put rate. Therefore, the installation of a SAS 82 in a precal-
ciner 58 that is designed for the appropriate momentum, angle
of swirl vane 100 and/or bluff body size or flare diffuser to
mix as much as possible of the gas riser duct or precalciner
flow into the high momentum swirling flow(s) before the centre
point of the duct is expected to reduce stratification and CO,
the O_2 level needed to eliminate CO and exit temperatures. In
turn, the addition of a SAS 82 should also result in a better
burnout of coal, petcoke or lump fuel improving fuel consump-

tion and the clinker output rate by increasing the calcination rate via the removal of the CO_2 boundary layer.

[0125]   The installation of a SAS 82 is further expected to reduce NOx, via reburning and staging. Introducing volatiles into the process gas flow at approximately 1000 − 1400°C should reduce NOx via the reburning reaction, providing there is a deficiency of O_2. The efficiency of the reburning depends on the temperature (the higher the better, 1200°C being a good level) and the local stoichiometry (0.85 is preferable). In addition, the staging of combustion, by allowing the coal volatiles to burn sub-stoichiometrically and re-introducing the remainder of the air afterwards, reduces NOx formation from oxidation of the nitrogen in the fuel. Therefore, both reburning and staging can be used in the cement making process to reduce NOx levels and even produce "Low NOx" cement kiln systems.

[0126]   The SAS 82 can make the strategy more effective since it may facilitate the burn out of char after the final exhaust gas by-pass system introduction if a precalciner SAS 124 is added to the kiln system. Where a kiln SAS 120 variant is added it will also increase the effectiveness of the strategy by ensuring that, if lump fuel is used for reburning, it is burnt out before the end of the calcination zone. In addition, the use of the kiln SAS 120 to facilitate fuel burn-out, will also help the reburning by producing a more uniform concentration of O_2 at the upper end of the kiln 46.

[0127]   By installing a SAS 82 downstream in the process gas flow from the injection point of ammonia in a plant operating the SNCR de-NOx procedure, the small amount of unreacted or "slipped" ammonia can be converted to NO, hence avoiding the dark plume formation and ammonia emission problems and allowing more ammonia to be added for a better degree of NOx reduction.

[0128]   In addition to all of the advantages listed above, the installation of a SAS 82 is also expected to reduce dioxins from an exhaust gas by-pass system. It has been observed

that when lump fuel is fed into the kiln feed shelf **38** or into
the precalciner **58**, the resulting poor burnout can lead to
dioxins being formed in by-passes. This has also been observed
where coal is used as a fuel. The potential for dioxin forma-
5   tion is due to unburned carbon or volatiles being carried up
the off-take **80** of an exhaust gas by-pass system and acting as
drivers for a *de novo* synthesis reaction. Therefore, the in-
stallation of a SAS **82** in the early part of the by-pass (in a
similar manner to a calciner or gas riser) should facilitate
10   the burn out of the unburned material and eliminate dioxin
formation.

[0129]   The installation of a SAS **82** may also improve the
clinker output in a kiln system **20**. The general use of the
range of SAS **82** facilitates a lower O_2 level within the kiln
15   system **20**; lower exit gas temperatures, better combustion and
better heat transfer to the solid material being processed.
Hence, as an alternative to taking up all of these advantages
to their fullest extent (exploiting greater levels of fossil
fuel substitution by alternative fuels or petcoke or seeking
20   lower NOx levels), an increase in clinker output rate can be
obtained.

[0130]   In the above text, although "fuel" has been dis-
cussed, it will be understood that combustible material, char
or volatile, can also arrive with raw materials. Either char
25   may survive passage through the preheater, or material with a
volatile fuel content may be fed to a lower stage of a prehea-
ter **20** or possibly to the precalciner **58** in order to reduce
episodes of volatile distillation and emission to air, that
might occur if such material were added nearer to the pre-
30   heater gas exit.

[0131]   Further, although the above embodiments discuss the
injection of air or gas, steam could, in principle, be in-
jected instead of or as well as air (although requiring more
momentum to achieve the same mixing effect), if conveniently
35   available under pressure. As will be understood, steam alone
will not provide the same levels of oxygen, however, this may

not be important in situations where producing the mixing effect may be the more important feature of the SAS **82**.

[0132]   It will be further understood that the invention is not limited to the embodiments described herein which are merely illustrative of preferred embodiments of carrying out the invention, and which are susceptible to modification of form, arrangement of parts, steps, details and order of operation. The invention, rather, is intended to encompass all such modification within its scope, as defined by the claims, including application to kiln systems producing products other than Portland cement clinker. Further, the invention is not limited to the use of a SAS **82** at only one point in a kiln system and circumstances may exist where a second (or more) SAS **82** system will add to the advantages and/or produce different advantages.

EXAMPLE

[0133]   A SAS system as described above has been successfully applied in a 4500 tpd off line calciner kiln system. The kiln was 84 m long and 5.2 m in diameter; the calciner had a volume of 350 m^3 with a gas residence time of 2.5 − 3.0 secs.

[0134]   Without the SAS, even at high oxygen levels that cause a drop in output rate, the calciner had significant CO problems, resulting in levels of up to 1500 ppm CO at the stack (corresponding to 10,000 ppm ex calciner at normal O2 levels of 2-3%). The high CO was thought to come from poor mixing, hence SAS was tried as a solution to the problem.

[0135]   SAS was installed with a 10,000 Nm^3/hr fan, which could supply at 2500 mm water gauge with the aim of resolving problems of CO generation due to poor mixing conditions. The system had 4 swirler flow injectors with 20 degree swirl vanes injecting on to a circle of 0.3R radius (R = calciner duct radius) and 2 swirler flow injectors directed on to a 0.5R circle (in the same plane) in a counter rotating manner, generally as illustrated in this text.

[0136]   A significant reduction in CO level of some 2500 ppm was achieved at the calciner and around 500 ppm at the stack, coupled with a drop in the concentration of NOx. Analysis of the carbon content in the hot meal feed to the kiln and the drop in CO indicated that a fuel saving of 1.5% was achieved. Analysis of the hot meal indicated a drop in LOI (loss on ignition) of 2 indicating better decarbonation of the feed%, which will allow an increase in output from the kiln. It was not possible to reduce the CO level to zero, due to the instability of the coal feed at the time of the measurements, as during some periods there was insufficient oxygen to burn the excess coal delivered transiently.

[0137]   It was further realized that there should not be any significant imbalance in the construction or performance of any injectors (when there is more than one of them). Differences in fabrication and significant differences in the layout of ducts connecting the fan(s) may resulted in different performance from each injector.